Cybershake NZ v18.6: New Zealand simulation-based probabilistic seismic hazard analysis

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1. Introduction

This poster presents the computational workflow and results of the June 2018 version (v18.6) of probabilistic seismic hazard analysis (PSHA) in New Zealand based on physics-based ground motion simulations ('Cybershake NZ'). In the current work completed to date, the Graves and Pitarka (2010, 2015) hybrid broadband ground motion simulation approach is utilized considering a transition frequency of 0.25 Hz, a detailed crustal velocity model with a grid spacing of 0.4 km, and the Campbell and Bozorgnia (2014) empirically-calibrated local site response model.

2. Computational overview

A total of 12,226 finite fault rupture simulations are undertaken and seismic hazard results computed on a spatially-variable grid of 27,481 stations, with distributed seismicity sources considered via conventional empirical ground motion models (as shown in Figure 1). We adopt a 'forward' simulation approach (as opposed to using reciprocity) because of:

a) Large number of stations relative to rupture realizations considered (i.e., 12,226 ruptures versus 27,481 stations).
b) Computational grid that is determined specific to each rupture in order to optimize the domain size for a targeted minimum ground motion amplitude.
c) Near-term intention to include plasticity.

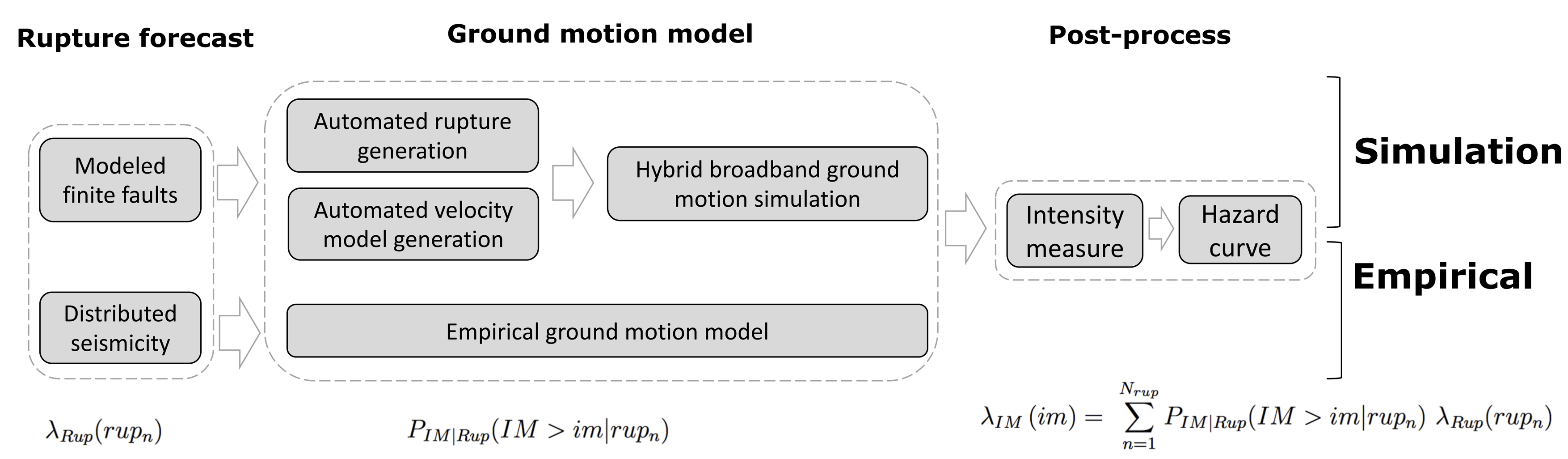


Figure 1: Computational workflow of Cybershake NZ v18.6.

3. Automated kinematic rupture generation

Automated generation of kinematic ruptures (using Graves and Pitarka 2015 method) based on the corresponding fault geometry, moment magnitude, rake angle, and hypocenter location is implemented as part of the Cybershake NZ workflow (shown in Figure 1). Figure 2 illustrates all of the shallow crustal faults from Stirling et al. (2012) considered in this study. Note that 8 subduction interface faults were excluded in v18.6 as the ground motion simulation validation efforts (in New Zealand and elsewhere) have mostly focused on shallow crustal events (e.g., Razafindrakoto 2018, Goulet et al. 2015). Considering the optimized scheme for generating simulation domains, 482 faults out of 528 shallow crustal faults in Stirling et al. (2012) model are considered in v18.6 Cybershake NZ. Figure 2 shows the surface projection of excluded sources in blue.

A Monte Carlo scheme is used to sample variability in the seismic source parametrization by varying the hypocenter location along the strike and dip directions, and slip distribution per each hypocenter realization. The total number of rupture realizations for each fault was based on the corresponding rupture magnitude, M_w, (shown in Figure 3b).

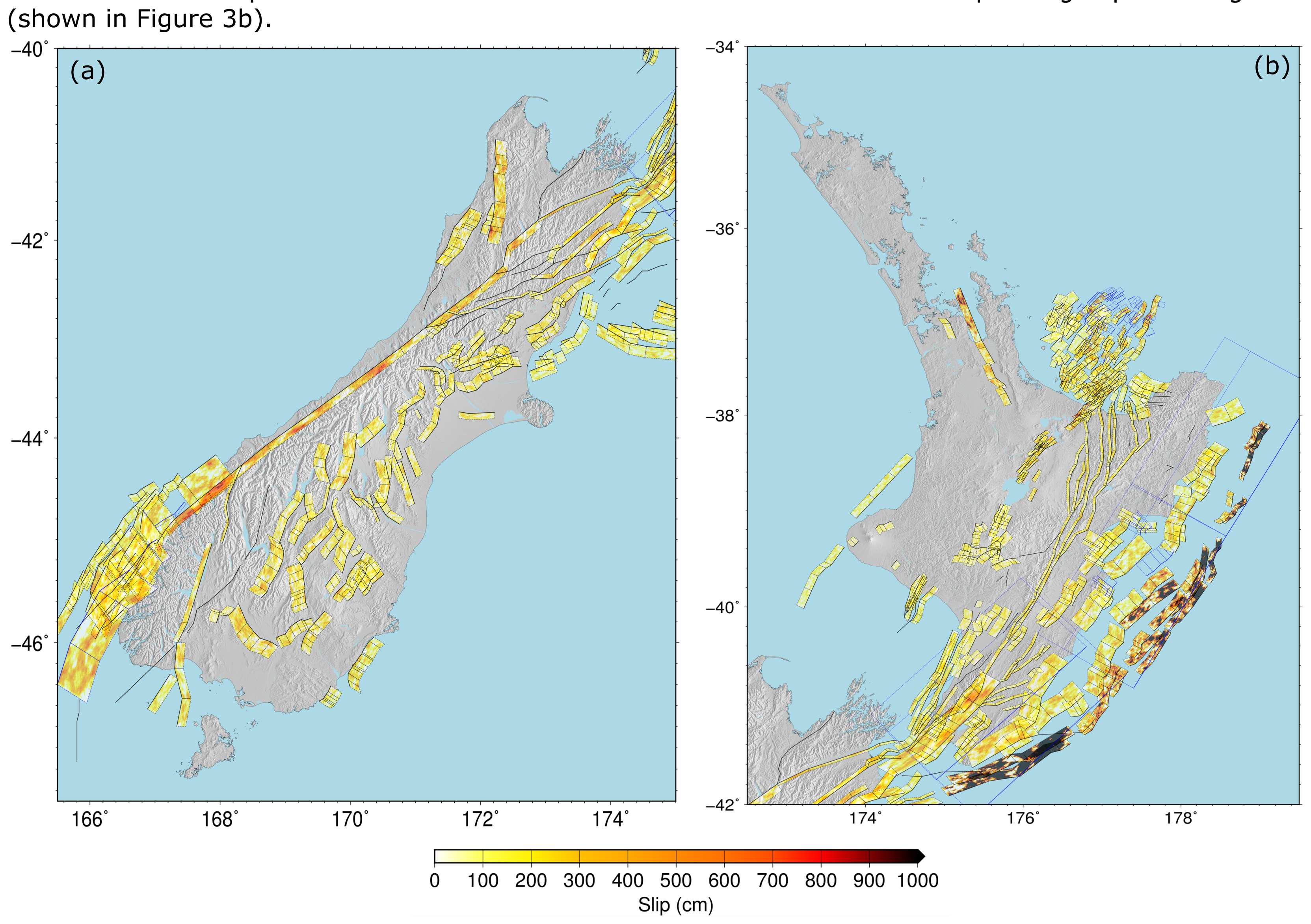


Figure 2: A kinematic rupture realization for each of the 482 shallow crustal finite faults considered in the automated rupture generation for v18.6: (a) South Island; (b) North Island. The surface projection of the excluded sources are shown in blue.

4. Automated simulation domain and computational demand

Simulation domains for the considered ruptures are generated utilizing a detailed velocity model of Lee et al. (2017) for the Canterbury region and Eberhart-Phillips et al. (2010) for the rest of New Zealand. The simulation domain for each and every fault is generated using an optimization algorithm which maximizes the land coverage of the simulation domain (in order to remove the unnecessary computational burden of simulating ground motions offshore). Figure 3a illustrates the initial and optimized domains for the AlpineF2K fault as an example among others.

Figure 3b presents the model utilized to determine the number of Monte Carlo realizations for the considered faults, given the their median M_w. The minimum value of 10 realizations are considered for faults with M_w smaller than 6. The core hours on the Nesi Kupe (skylake processors) HPC to conduct simulations at the optimized domains with 0.4 km grid size and varying total duration are also presented in Figure 3b. In total, ~150,000 core hours are spent for v18.6 runs.

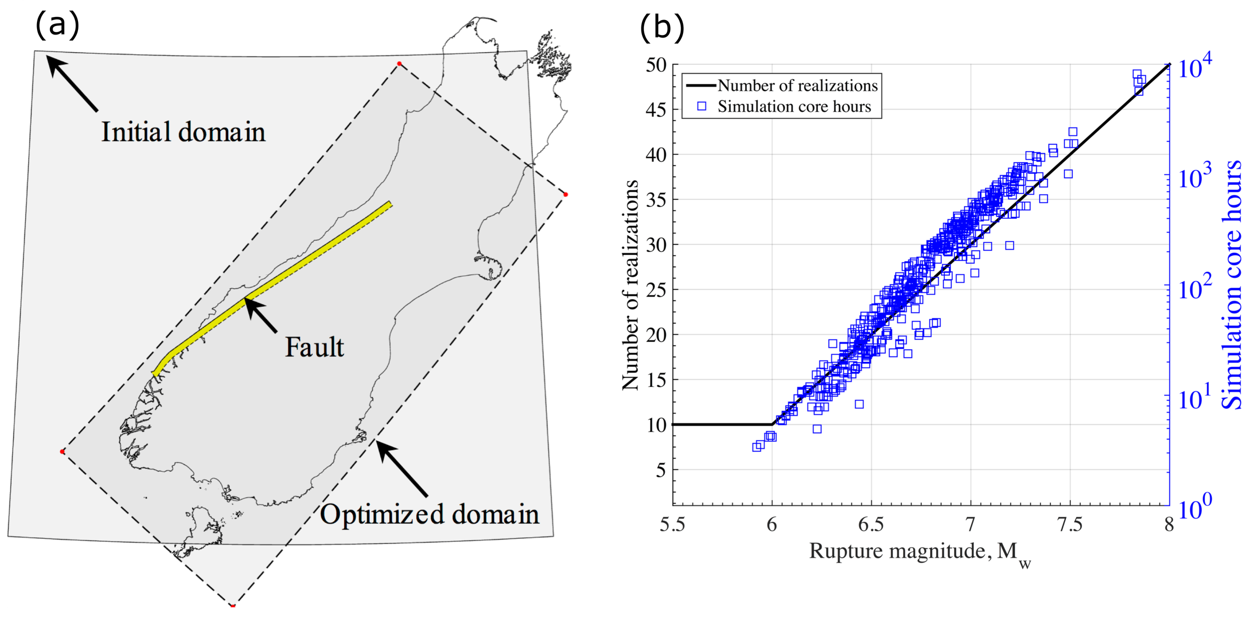


Figure 3: (a) Optimized simulation domain generation; (b) the model utilized to determine the number of realizations per each fault based on rupture magnitude and the corresponding computational demand.

5. Ground motion recording sites

In order to have a consistent grid of points on the surface to store the simulated ground motions and combine the results to obtain seismic hazard, a nation-wide grid of recording stations is generated (as shown in Figure 4a-b), which also includes all the real strong-motion stations of GeoNet.

This grid has a non-uniform spatial density which is a function of population density and sub-surface soil condition. The population data provides an appropriate constraint to have a coarser grid size in mountainous regions, and finer grid sizes in highly populated regions (which provides a robust means for site-specific PSHA). Considering the depth corresponding to the time-averaged shear wave velocity in the top 30 m (V_{s30}), a denser grid is also placed in regions with soft sub-surface soil. Figure 4c-d presents the median V_{s30} values at the generated recording sites from Foster et. al. (2018), utilized in both empirical- and simulation-based PSHA.

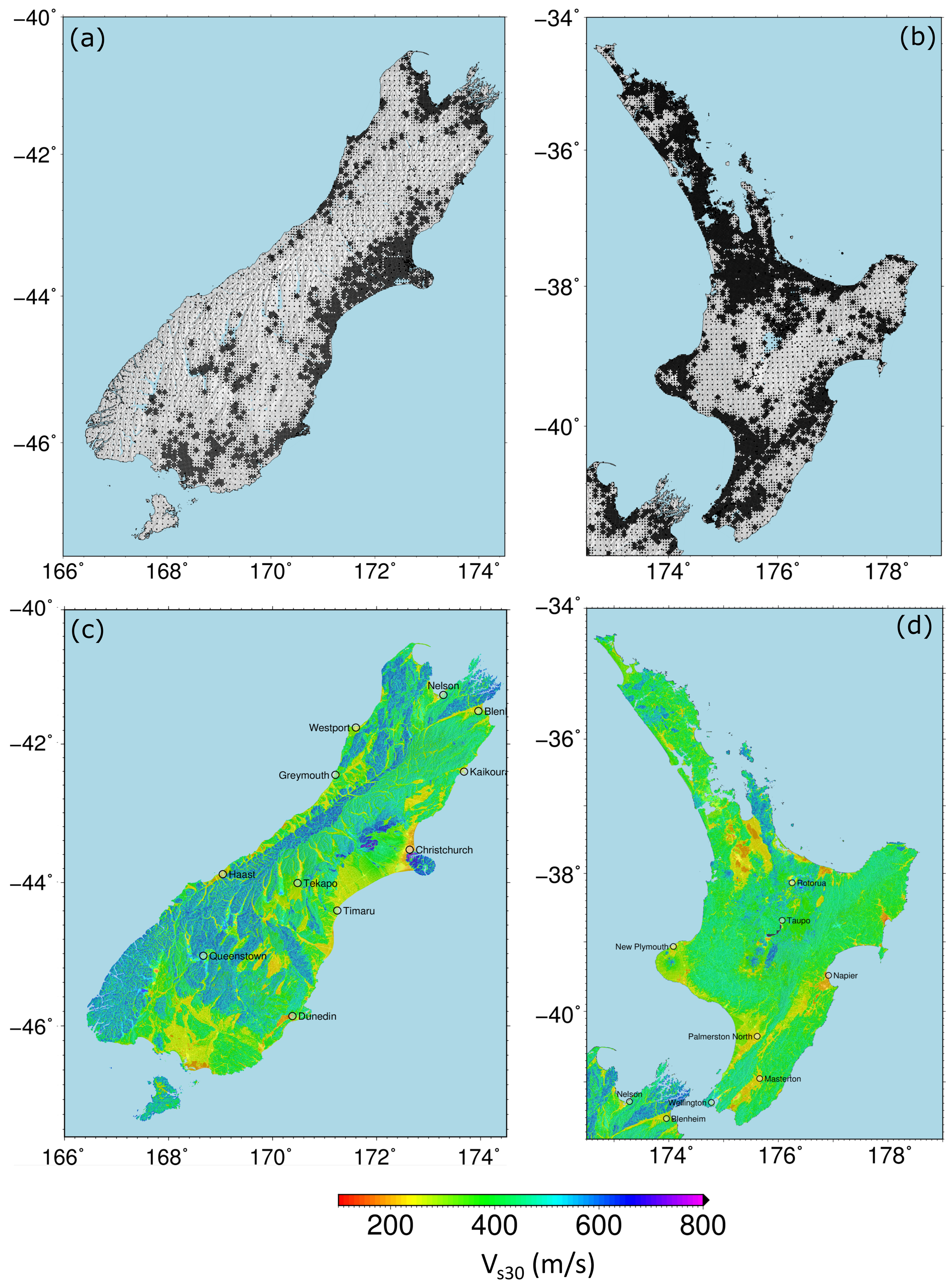
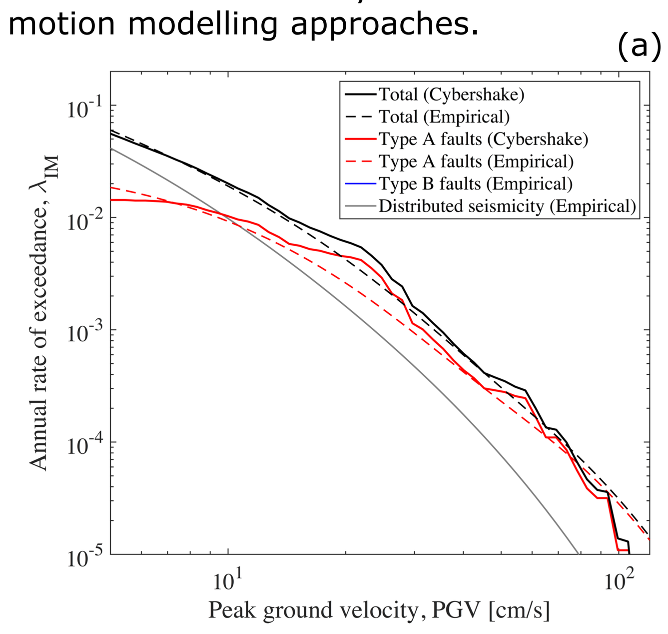
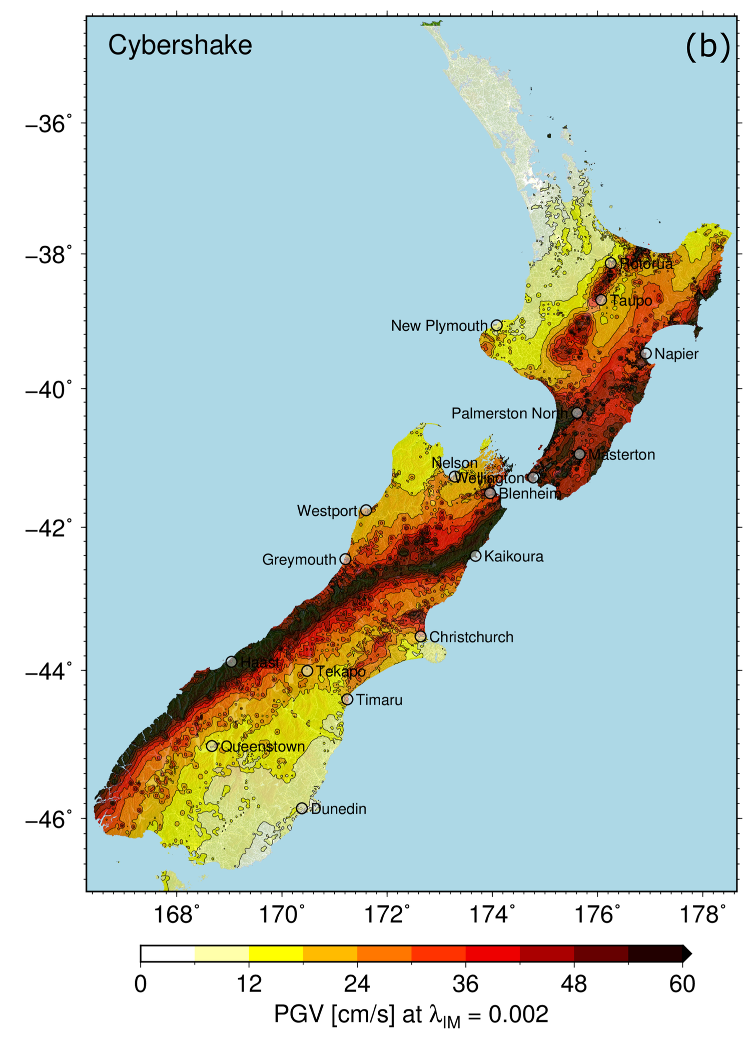


Figure 4: a-b) Non-uniform grid generated based on population density and sub-surface soil condition; c-d) corresponding V_{s30} values from Foster et. al. (2018).

6. Seismic hazard curve and uniform-hazard ground motion map

Figure 5a presents the hazard curve for a location in the Canterbury region from Cybershake and empirical ground motion models, indicating the need to include more parametric uncertainties in the simulation to appropriately represent the site-specific hazard (e.g., sampling rare ground motion levels). Figure 5b-d present the uniform-hazard PGV maps (at 10% in 50 years exceedance level), indicating region-specific differences between the Cybershake and empirical ground motion modelling approaches.





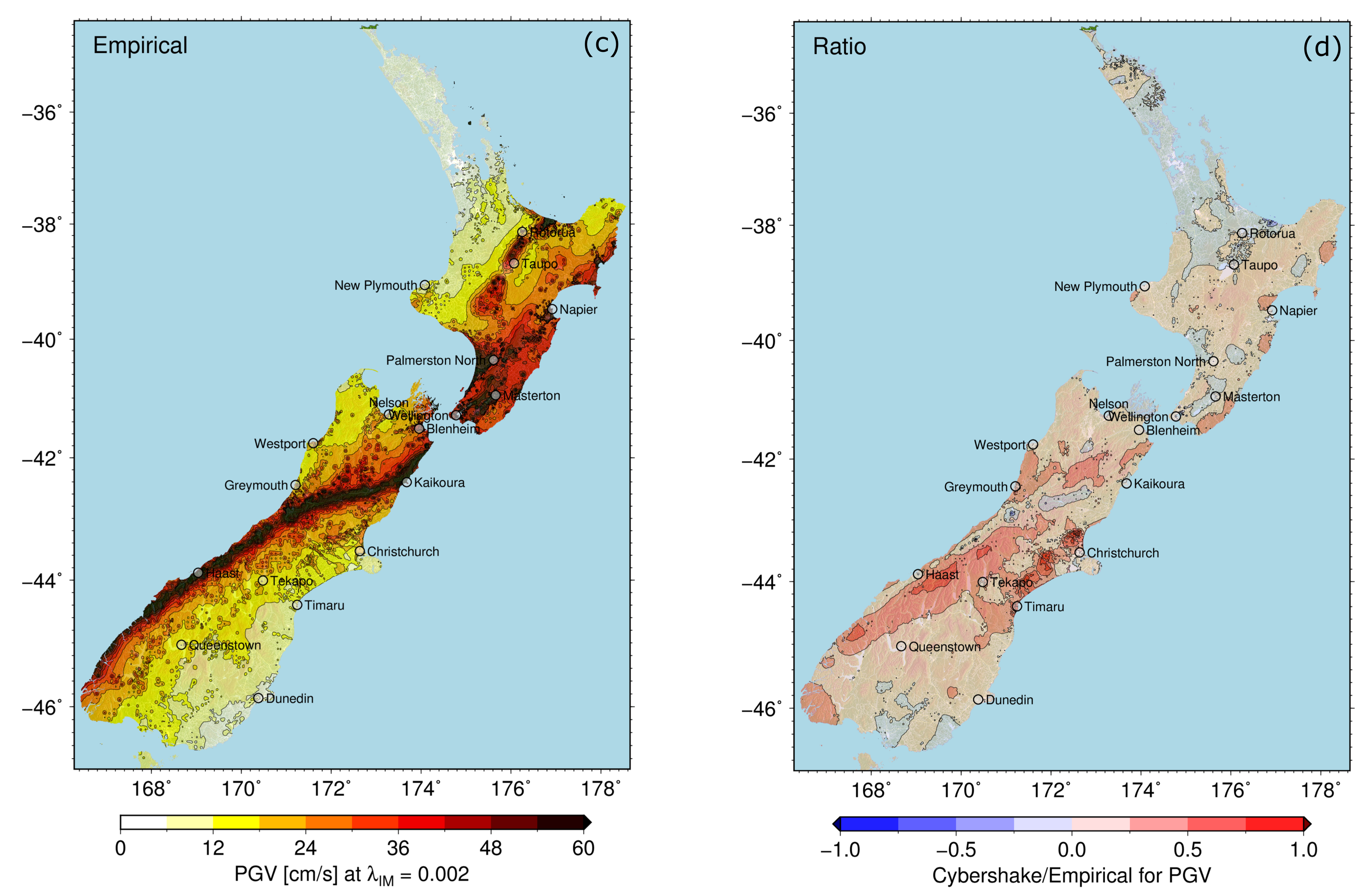


Figure 5: (a) PGV seismic hazard curve of a site in the Canterbury region; (b-c) PGV maps corresponding to 10% in 50 years exceedance level from Cybershake and empirical ground motion models; (d) log (Cybershake/empirical).

8. Future work

The aim of the current version was to develop the computational pathway for simulation-based PSHA in New Zealand. We plan to consider more exhaustive uncertainty treatment for each source (i.e., hypocenter, slip, rupture magnitude), include subduction ruptures, and increase the frequency limit of comprehensive physics-based simulations. Cybershake NZ is considered as one of the alternative approaches in the logic tree method to address PSHA epistemic uncertainty, with the corresponding region-specific weight coming from validation studies on ground motion simulation results in different regions of the country.